Algorithm Design for Networked Information Technology Systems

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Algorithm Design for Networked Information Technology Systems

With a Foreword by Dr. C.V. Ramamoorthy, Professor Emeritus

With 161 Figures

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Cover illustration: ADDM algorithms encapsulate a fundamental microcosmic design principle that governs the organization of complex, real-world phenomena: astronomical systems, world civilization, computer electronics, and biological systems.

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In Memory of My Loving Parents

Foreword

I felt deeply honored when Professor Sumit Ghosh asked me to write the foreword to his book with an extraordinary perspective. I have long admired him, first as a student leader at Stanford, where he initiated the first IEEE Computer Society's student chapter, and later as an esteemed and inspiring friend whose transdisciplinary research broadened and enhanced the horizons of practitioners of computer science and engineering, including my own. His ideas, which are derived from his profound vision, deep critical thinking, and personal intuition, reach from information technology to bioscience, as exhibited in this excellent book. To me, an ordinary engineer, it opens up a panoramic view of the Universe of Knowledge that keeps expanding and inspiring, like the good Indian proverb, which says, "a good book informs you, an excellent book teaches you, and a great book changes you." I sincerely believe that Professor Ghosh's book will help us change and advance the methods of systems engineering and technology.

Vision

Inspired vision sees ahead of others what will or may come to be, a vivid, imagined concept or anticipation. An inspired vision personifies what is good and what like-minded individuals hope for. Our vision is one of creating an Internet of minds, where minds are Web sites or knowledge centers, which create, store, and radiate knowledge through interaction with other minds connected by a universal shared network.

This vision will not just hasten the death of distance, but will also incarcerate ignorance. We note that the rapid growth of many disciplines in the sciences, humanities, technology, and business, has been promoted by the convergence of ideas through knowledge transfer across traditional boundaries. This is what a distinguished business leader and entrepreneur, Professor George Kozmetsky, calls the transdisciplinary movement in education. Professor Ghosh is a great mentor, who teaches by this principle. In some sense, knowledge transfer across traditional disciplinary boundaries is the first phase in the Internet of the Mind paradigm.

Preliminary Issue

A critical and difficult to resolve issue is how to fine tune educational processes and maximize the flow of educational information from the source—the transmitter (knowledge bases, mentors, books, teachers, etc.)—to the needy individual, the student at the receiving end. These processes must ensure that the recipient obtains the needed education in the most effective way at the most appropriate time and place. Two issues are paramount here: The first is how to make knowledge "fluid" ; the second is how to personalize educational processes to fit the intellectual infrastructure of the recipient. The concept of fluidity is similar to the Keynesian concept of liquidity of capital, which makes knowledge easily storable, transferable, and transportable across heterogeneous intellectual boundaries. The second issue will be addressed later.

Knowledge and Technology: Their Growth and Implications

We shall now tread on the unknown and unexplored area of knowledge and technology growth. We are fully aware of their exponential growth rates, but unfortunately, there are no precise methods or rigorous approaches to measure them. A Harvard Business School study many years ago found that "knowledge doubles every seven years." More recently, former U.S. President Bill Clinton and Vice President Al Gore have indicated in their speeches that knowledge doubles every three years, and they refer to U.S. Department of Education studies.

The technology growth rate can be surmised from the progress of the high-tech semiconductor and communication industries. The famous Moore's law states that semiconductor chip performance doubles every eighteen months; while the price stays the same. Thus, we shall assume that the knowledge growth rate based on "expert" evaluation is about 30% per year; likewise, the technology growth rate based on Moore's law is about 66% per year. In a later section, we shall try to answer an apparent anomaly: Why is the growth rate of technology (which is derived from knowledge) much higher than the growth rate of knowledge itself?

Knowledge Obsolescence Rates

Bill Joy, the chief scientist of Sun Microsystems, has surmised in his featured interviews and articles that professional obsolescence creeps at the rate of 20% per year. In other words, after five years, we will be strangers in our professional disciplines, no better than college freshmen. One may quibble about the magnitude of the rate, but the trend appears to have some validity. This obsolescence figure may be more applicable to mature professionals beyond the age of 40 who have not actively kept up with technological advances than to younger ones.

Technology Growth, Knowledge Growth, and Moore's Law

Technology is derived from scientific knowledge, but Moore's law tells us that technology grows much faster than knowledge. We shall offer a subtle explanation. Knowledge is a result of rational and physical discoveries. These processes can be slow and incremental, but they rarely leapfrog. Knowledge and its discoveries are like dots on the radar screen in an air traffic control center: New dots appearing, old dots always moving and changing. Technology is derived from connecting and linking the dots and creating useful patterns that can be made from them. It is like knitting a beautiful mosaic that connects and provides meaning (satisfies human needs) to the patterns. Given N dots (e.g., knowledge discoveries or inventions), the number of patterns they create is an exponential power of N. This heuristically explains Moore's law and the more rapid growth of high-tech industry. The dots and patterns are always moving and changing, and this also is a prominent characteristic of technology. Technology always advances faster than knowledge. The former subsidizes its own growth and that of science through the creation of automated tools and computer-aided adjuncts. This, in turn, fuels the accelerated growth of technology, à la Otto Hahn's chain reactions and the Livermore loops.

The Challenge

Our real challenge: how to develop a feasible and realizable approach to reducing the nonlinearly growing chasm between the advancement of technology and the increase in the knowledge content of any individual. In theory, the chasm cannot be completely and conclusively bridged. Although this raises many unanswered—and perhaps unanswerable—questions, several approaches that can slow down the overtake and obsolescence are conceivable. A key approach is compression of learning time by innovative teaching methods, which underscores the need to personalize educational processes to fit the intellectual infrastructure of the recipient. In this book, Professor Ghosh proposes interdisciplinary approach as the fundamental source of new teaching techniques. This transdisciplinary approach is fluid-like and flexible, allowing one to easily penetrate a number of different disciplines at once. The objective of a proper match between the knowledge generators and knowledge recipients is analogous to the issue of impedance matching in electrical engineering, which ensures an efficient transfer of electric power from the power-generating stations to the power-consuming towns. The objective is also critical because it holds the key to opening a path for every willing individual to continue to be an active and valuable participant in society, despite the march of time. We are now living longer and healthier lives and working for many more years, and the idea of mandatory retirement has clearly fallen from grace. This then propels us to envision an environment and an educational framework in which a new knowledge infrastructure may be established in each individual to help him or her remain matched with the advancing technology. It then becomes the purpose of the environment and educational framework to provide caring and personalized mentors to help in the assimilation of new technologies; casting them in the molds of individuals' infrastructures for ultrafast absorption. Even as each of us ages with time, the promise that we can continue to keep pace with exciting new technologies and remain valuable and contributing members of society as long as we wish is a shining beacon of hope.

The Three Visions and Their Manifestations in This Book

Through many decades of my association with academic research and teaching, I have come to a firm belief that the interplay of three types of vision is critical for progress. These include (1) eagle vision, (2) frog vision, and (3) fish vision. The eagle soars high, has a commanding view of the entire ground in every direction, and, when necessary, is able to bring its eyes to a pinpoint focus on a scurrying rat, miles below. In this book, the eagle-eye vision constitutes the overview, a survey, a perception about the integrated whole, from the past, the present, and the future. Frog vision refers to microscopic vision, or an up-close view of an object that reveals an extraordinary level of detail. Here, the frog-eye vision is manifested in the details of the algorithms, methods, and concepts that the book articulates so well. The fish views the entire world outside the water, all 180 degrees, compressed through a narrow cone of 98 degrees. However, its vision can detect fast changes because its eyes' fields of vision do not overlap; and the fish cannot afford to shut its eyes even for a moment. The fish-eye vision assumes the form of an emphasis on the dynamics of change and movement and the inevitable progress and advances that the book will produce.

This book is not just for specialized scientists and engineers; its essence is easily accessible to the nonspecialists who will find their curiosity aroused, their need to learn stimulated, and their minds changed.

Dr. C.V. Ramamoorthy, Professor Emeritus
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April 3, 2003

Preface

Overview

Networked information technology (NIT) systems, also referred to as network-centric or net-centric systems, are already pervasive and promise to become even more encompassing, powerful, highly capable, and greatly useful in the future, touching nearly every element of human endeavor and society. Already, today, NIT systems underlie much of e-commerce, banking and financial transactions, online airline reservation systems, worldwide communications, distance learning, and remote data acquisition and control, to name a few. In the near future, NIT systems will encompass patient medical records, remote surgery, intelligent transportation systems (ITS), communications and control in deep space, and innumerable innovative services and products, limited only by our imagination. Under the Future Combat Systems (FCS) program, the U.S. military, especially the U.S. Army, is committed to a total transformation to bring itself in line with the new network-centric warfare idea. Under the emerging Homeland Defense program, the objective is to preempt threats and attacks on the nation through processing a tremendous volume of intelligence data from a large number of diverse sources, without becoming overwhelmed from information overload, and coordinating the activities of geographically dispersed public safety agencies in a precise, accurate, and timely manner. Fundamentally, in an NIT system, first, the relevant data are identified and acquired from geographically dispersed points; second, the raw data are transformed into usable information through computational intelligence techniques; and third, the information is disseminated to other geographically dispersed regions, as needed. The traditional, uniprocessor-based, centralized algorithms cannot represent NIT systems faithfully and are, clearly, inadequate and unnatural. Synchronous distributed algorithms are equally inappropriate because they represent a simple extension of the centralized approach. Asynchronous, distributed decision-making (ADDM) algorithms constitute the most logical approach to serve as the underlying control of NIT systems and is the subject of this monograph.

NIT systems are complex, as opposed to toy academic problems, and are intended to operate in the real-world environment. If the incredible potential of the information age is to be brought to fruition, NIT systems must be designed precisely and operated correctly. This, in turn, requires the development of a new scientific and pragmatic approach. When designed correctly and effectively, NIT systems may last a very long time, perhaps 50 to 150 years. The consequences of failure may be serious, ranging from unnecessary loss of lives to a collapse of the public's confidence. As an example, consider VHDL, a very high-speed integrated circuit hardware description language, that was intended to be a state-of-the-art tool to describe and validate any electronic design accurately and efficiently. Initiated in 1985, a billion dollars has already been invested in the VHDL effort by the government and industry. However, its most basic objectives—accuracy and efficiency—that were mandated in its specifications back in 1985, are far from being realized. More important, its limitations have done little to facilitate the growth of innovative and complex design capability. The principal cause underlying the inadequacies of VHDL may be traced to the incorrect application of the notion of timing to hardware systems that are intrinsically asynchronous and distributed.

As a second example, consider the following occurrence in New Jersey involving the E-ZPass system [1], a cashless toll collection system for interstate highways. Motorists are required to purchase magnetic toll cards of specific dollar values and place them on their visor. When passing through the toll booth at a maximum speed of 15 mph, the toll is magnetically deducted from the card and the driver passes through the toll booth. For a period of time following the installation of E-ZPass, motorists received in the mail citations from the New Jersey Department of Motor Vehicles for speeding along the toll highways in excess of 80 to 150 mph. Apparently the E-ZPass system was being used to record the times a vehicle passed through the toll booths, from which the elapsed time between two successive toll booths was calculated and the car's speed computed. The only problem was that many of the cited drivers were driving older vehicles that were not even capable of running faster than 65 mph. Protests by the cited drivers were initially met by stiff official resistance, but when an investigation was eventually launched, it was revealed that the clocks in the different toll booths in the E-ZPass system were never synchronized. The architects responsible for computing the vehicle speeds had overlooked the basic notions of timing and clock drifts in distributed systems.

For a third example, consider the worldwide Internet whose spectacular growth and success are rapidly being dwarfed by its lack of security, underscored by its fundamental inability to track IP packets and prevent denial-of-service attacks. Triggered by the events of September 11, 2001, fueled by the belief that the Internet may have been used by the terrorists for money laundering, and threatened by the fear that dramatic cyberattacks are not preventable, increasingly, courts and corporations are attempting to wall off portions of cyberspace. In so doing, according to Lessig [2], they are destroying the Internet's potential to foster democracy and economic growth worldwide and ending the Internet revolution just as surprisingly as it began.

Relative to the Internet and in the light of the growing attacks on the Internet from computer viruses worldwide, even reputed scientists and corporate executives of leading NIT companies have acknowledged, publicly and privately, that the Internet is far too complex to secure. At the NSF-sponsored workshop on the Modeling and Simulation of Ultra-Large Networks: Challenges and New Research Directions, held at the Sheraton in Tucson on November 19-20, 2001, the consensus among thirty top-flight researchers from the areas of network design, simulation modeling and analysis of networks, and modeling and simulation methodology was that the key principles underlying the successful scaling of the Internet are neither known nor understood. For the sake of science and our progress towards the future, respectfully, this is not acceptable. We conceived and designed the Internet and we must understand it. Lawson [3] traces the origin of the complexity in the computer industry to the deployment of compromised hardware design for all types of computing, leading to the demand for unprecedentedly complex system software that, despite involving thousands of code developers, was never completely understood. Leading researchers from the top telecommunications companies [4] have expressed their serious concern over the occurrence of inconsistencies and failures in the context of feature interactions and the current inability to understand and reason about these events. For example, while private telephone numbers are successfully blocked from appearing on destination caller ID screens under normal operation, as they should be, these private numbers are often unwittingly revealed during toll-free calls [5]. As a second example, despite the telephone subscriber paying a monthly fee for the caller ID service, incoming phone calls from the outside, including those initiated by the local telephone service provider, often show up as out of area on the consumer's caller ID display. Under such difficult circumstances, the scientific tradition recommends that we not be overwhelmed, but rather search for the fundamental principles that are usually few in number, easy to comprehend, and on which all systems, regardless of their complexity, are based. The goal of this book is to uncover these fundamental principles, where possible, in the form of ADDM algorithms. The vision underlying this book finds support from four recent discoveries.

The first is our proven ability to successfully design and operate digital computers consisting of millions of logic gates. Despite the bewildering number of gates, the key principles underlying the success are (i) there are only a handful of different types of gates, (ii) each gate is a self-contained entity [6] whose behavior and interactions with other gates are simple and well understood, and (iii) the gates are organized hierarchically to successively build bigger and more complex building blocks. The second is the discovery that underlying the perplexingly complex behavior of an ant colony, consisting of hundreds of thousands to millions of ants, are only a few types of ants—queens, foragers, guards, etc.—and that every ant within any given type is guided by a few simple rules. The third is the discovery by geneticists that, despite the overwhelming number of genetic combinations that are conceivable in the millions of lifeforms, Nature employs only a limited number of genes, repeatedly using them over and over to create a seamless ocean of different lifeforms. The fourth is the growing acceptance among geologists that behind all the complex and bewildering physical changes we see at the earth's surface, is an underlying simple set of principles, the key being the mantle's massive heat engine that drives the tectonic plates. The inspiration from these discoveries is that underlying the highly complex yet successful systems may be a set of constituent elements that are well defined and interact through simple, provably correct rules.

The motivation for precision in NIT system design comes from another most unusual and unexpected source, namely, law enforcement. The rapid proliferation of NIT systems in society and the growing concern over how to prosecute increasingly sophisticated NIT-related crimes, coupled with the socially accepted, strict, legal threshold implied in beyond reasonable doubt, virtually necessitates precision in every phase of NIT systems design. Conceivably, spurred by law enforcement, legislation may enact laws mandating precision in NIT systems.

Careful analysis of the VHDL and E-ZPass examples and other difficulties in the distributed systems literature points to deeper problems. In the article titled, "Parallel Processors were the Future ... and May Yet Be," in IEEE Computer (December 1996), Michael Flynn of Electrical Engineering at Stanford University observes candidly that the promise of parallel processing has not been fulfilled. He notes two primary reasons. First, for most science, the mathematical representations were developed largely in the nineteenth century, and they represent a simplified idealization of reality. Second, and more important, the mathematical modeling reflects the human reasoning process as sequential. Flynn's observation is true, as evidenced by the fact that although most real-world, large-scale, computing-based systems today are driven by centralized algorithms, the literature in electrical and computer engineering, computer science, and operations research is dominated by centralized algorithms and synchronous distributed algorithms. As stated earlier, the latter constitutes a logical extension of the centralized approach and inherits the same fundamental limitations. Examples of the use of centralized and synchronous distributed algorithms may be found in payment processing, airline reservation systems, inventory management, traffic control, etc. Flynn's two reasons may be complemented by a third reason, namely, our desire to find a simple parallel approach that applies to all problems, quickly and uniformly.

The real world, however, is complex and much like fractals. The deeper we dive and the greater our desire to understand the fundamentals in depth, the more complex it gets. It is, therefore, no surprise that the desire to uncover a simple parallel approach that applies to all problems has not yet been realized. In truth, if such a simplistic approach did exist, life for us scientists would be boring, uneventful, and uninteresting. There would be no room left for challenges or creativity.

Anil Nerode of the Mathematics Department at Cornell University observes that among traditional engineering and computing research personnel, given a real-world problem, there is a strong tendency toward quickly establishing a mathematical model. Because the model is subject to the available analytical manipulation tools, a belief develops that the real-world problem has been successfully rendered amenable to rigorous mathematics. Nerode points out that this belief may be misplaced in that the very process of deriving a quick mathematical model strips the real-world problem of its essential characteristics. Thus, the mathematical model is grossly approximate. In contrast, an effort to develop a physical model of the problem may be far more challenging, but it is likely to yield highly accurate and realistic results.

Aim and Scope

This book presents a radically different paradigm, one where the basic premise is to precisely understand and accurately model real-world NIT systems, in their true form, to the best of our current ability. The paradigm begins with the recognition that many of the classical mathematical representations and models that we have grown up with since the nineteenth century may not apply meaningfully to the complex NIT systems of today. Practical examples include computer networks such as the Internet, banking infrastructure, credit card transaction processing networks, and inventory management systems. Second, the lens of the sequential human reasoning process through which we learned to view reality may not always provide the correct view of the world.

The author's pursuit of key problems from a number of disciplines ranging from hardware description languages, networking, inventory management, military command and control, and banking to intelligent transportation systems, and the synthesis of innovative control algorithms has serendipitously revealed this unique insight: that there is a fundamental micro-cosmic design principle of this universe, an archetype that extends from the astronomical-sized galaxies down to the minutest atom in the universe. At any level of abstraction, the subsystems of a system inherently possess independence, autonomy, and their own sense of timing; where they interact with each other, the interaction is asynchronous. The independence of each subsystem with respect to all others poses no paradox. It refers to the fact that the existence of a subsystem is independent of all others. Thus, even when a star undergoes a supernova, the rest of the universe continues to exist, although it may be subject to the flying debris and radiation from the dying star. Furthermore, at any level of abstraction, while the behavior of the subsystems and the interactions between them may be encapsulated through relatively simple rules, the repeated application of these rules to increasing numbers of constituent elements gives rise to systems of increasing complexity. In the discipline of biology, according to Franklin Harold [7], every cell constitutes a unitary whole, a unit of life, and a tremendous diversity of complex lifeforms results from the interaction of a number, say N, of cells that come together, where N may range from two to millions, or more. Although there may be data and information dependency between two or more subsystems of a system, each subsystem possesses its own processing or decision-making engine. The interactions enable the subsystems to learn, grow, and evolve.

This book develops and presents ADDM algorithms as an encapsulation of the universal micro-cosmic design principle, serving in the role of the underlying control and coordination of NIT systems. It develops ADDM algorithms as a systematic, scientific, and canonical approach to the design and analysis of NIT systems. In essence, however, ADDM algorithms may constitute the scientific core of any real-world system. An ADDM algorithm that is successfully designed for a given NIT system reflects the higher meta-level purpose or intent of the system while underlying the behavior of every constituent subsystem. Metaphorically, the ADDM algorithm represents the big picture, the bird's-eye view of the total NIT system behavior. Prof. C.V. Ramamoorthy of the University of California, Berkeley, refers to this as eagle vision. In the classic Public Broadcasting Service (PBS) television interview with Bill Moyers titled, "Joseph Campbell and the Power of Myth," Joseph Campbell rephrases the philosopher Schopenhauer: In this universe, everything [including every human life] influences everything else as if all lives are the dream of a single dreamer in which all the characters are also dreaming. Campbell describes the idea of the net of gems, also known as the net of Indra, the king of gods, as one where every life is represented as a gem, every gem reflects all others, and all gems are rising, spontaneously, simultaneously, and in harmony, as if there is an intention of cosmic proportion behind it. Fundamentally, the goal of ADDM algorithms is to encapsulate the intent underlying any complex real-world system in a systematic scientific manner. ADDM algorithm design represents an integrated exercise in both top-down design, where one starts with an intended overall behavior and attempts to synthesize the behaviors of the constituent lower-level entities, and a closely knit bottom-up phase, where the focus is on the design of the traits of the individual entities, such that together they yield the intended high-level behavior. The ADDM algorithm design effort is generally accompanied by a validation effort—a testing of the theory under realistic conditions before developing and deploying the actual system—through modeling and asynchronous distributed simulation of the underlying NIT system under ADDM algorithm control.

The content of this book is based on actual research and the experience of the author and his research group over the past twenty-two years, acquired through conceiving, building, testing, and analyzing real-world systems across a number of diverse disciplines. This book stands apart from virtually all of the books currently available on distributed algorithms in that it views asynchronous distributed algorithms in their true natural form. No constituent entity is presumed to possess any kind of global knowledge. In contrast, most of the currently available books cast distributed algorithms in the light of centralized thinking and frequently refer to concepts such as shared variables, global snapshots, knowledge of every state of a system at every time instant, awareness of deadlock in the entire system, asynchronously connected processors maintaining communication with a central facility, and certainty of distributed termination, all of which fundamentally contradict the essence of asynchronous, distributed, real-world systems. A likely reason may be that the authors of these books analyze the problems, understandably, through sequential reasoning and then inadvertently presume that the constituent entities have access to the authors' global knowledge of the problems. The authors of several books reveal a keen underlying desire to bring inherently asynchronous real-world processes under synchronous control, arguing that synchronous algorithms are simple to design. In one book in particular (*Parallel and Distributed Computation: Numerical Methods*, by Dimitri P. Bertsekas and John N. Tsitsikilis, ISBN 0-13-648700-9, 1989), the authors write, "it is quite hard to synchronize a data communication network and, even if this were feasible, it is questionable if the associated overhead can be justified." Clearly, the fundamental truth that geographically dispersed, inherently asynchronous systems may never be accurately encapsulated by synchronous algorithms and global synchronization is lacking.

Organization and Features

Chapter 1 defines NIT systems and ADDM algorithms and explains their relationship following a review of the current distributed systems literature and a critical analysis of the current computing paradigms. Chapter 2 presents the nature and fundamental characteristics of ADDM algorithms in light of how they influence and relate to each other and together solve the challenges underlying the NIT system. These principles are neither esoteric nor meant for toy academic problems. They are simple yet canonical and apply to actual problems in the real world. The U.S. Defense Advanced Research Projects Agency (DARPA) [8] observes that today's complex systems pose a formidable challenge in the form of scalability of the underlying control algorithm. A solid understanding of the principles, presented in Chapter 2, is the only known scientific approach today; by applying them, one may synthesize precise ADDM algorithms for NIT problems that will function correctly if the number of constituent entities were to increase from 10 to 50 or 5,000 or even 100,000, subject to other design limitations.

Chapter 3 presents a series of actual case studies in which ADDM algorithms have been successfully synthesized for a number of NIT systems, implemented through large-scale distributed simulations, and subject to performance analysis. The scope of the problems ranges from distributed discrete-event simulation of hardware description models in VHDL, railway networks, international payment processing, military command and control, fault simulation of digital systems, domestic payment processing in a partially connected network of banks, and a hierarchical distributed dynamic approach to inventory management. As evidence of the real-world nature of the problems studied, consider the following anecdote. The U.S. Department of Transportation (DoT) had recently commissioned [9] the Institute for Simulation at the University of Central Florida to review all of the commercial simulators manufactured in the United States and abroad and the MIT-developed simulator for the Boston Tunnel project, to examine their suitability for autonomous simulation of a large number of drivers and vehicles. The Institute evaluated a total of 51 simulators and provided a short list of 11 simulators that they felt met the DoT's criteria. After closer examination, the DoT concluded that neither of the commercial simulators in the short list nor the MIT-developed simulator satisfied its needs. In contrast, the DICAF algorithm [10] [11] developed by the author's research group has been successfully validated through an asynchronous distributed simulator executing on a network of more than 65 Sun spare 10 workstations, for a total of 45,000 autonomous vehicles representing a highly congested traffic scenario in Rhode Island.

Chapter 4 details key issues in debugging complex NIT systems. Chapter 5 argues the crucial importance of proofs of correctness for ADDM algorithms and presents techniques to develop such proofs. Chapter 6 presents a mathematical framework for synthesizing ADDM algorithms, starting with a centralized algorithm, and illustrates it for a specific military command and control problem. Chapter 7 reviews the conventional approach to performance analysis of distributed systems and presents a radically different paradigm for ADDM algorithms. Chapter 8 argues the need to perform perturbation analysis. It presents key principles and reasoning and describes results obtained from the stability analysis of representative ADDM algorithms. Chapter 9 recognizes the need for creativity and imagination in the synthesis of ADDM algorithms, argues from logical principles the role that high-quality interdisciplinary thinking may play in realizing this goal, and presents new techniques to instill such thinking in future NIT engineers and scientists. Finally, Chapter 10 summarizes the book and presents some reflections on the benefit and impact of ADDM algorithms in the future.

Audience

This book has been developed with three types of audiences in mind and has been written to facilitate straight-to-the-point, intense, and in-depth self-study. The only prerequisites are knowledge of the basic principles of physics and mathematics, logic, common sense, and a serious desire to learn. First, this monograph is a reference book intended to serve as a reader for a graduate- or senior-level undergraduate course titled, "Algorithm Design for NIT Systems" within the traditional computer engineering program or a new program such as the one in Networked Information Systems Engineering currently being developed at Stevens Institute of Technology. The monograph's intent is to constitute a key starting point for developing a theoretical and practical understanding of NIT systems in doctoral, graduate, and advanced undergraduate students who plan to pursue a career in NIT system design. It presents a scientific and pragmatic approach, developed in a canonical fashion, focusing on the underlying physical meaning and the fundamental mathematical reasoning, unlike the tradition of a purely mathematical treatment that is often devoid of pragmatics. The author hopes that the book will not only help students learn how to design, operate, maintain, and evolve NIT systems precisely but also inspire them to take on the role of leading thinkers and guide the evolution of the information age. In addition, the newly created interdisciplinary programs in NIT and business management, such as the Howe School of Technology Management at Stevens Institute of Technology (Hoboken, NJ), the Indian Institute of Information Technology and Management (Gwalior, India), and the Jerome Fisher Program in Management and Technology at the University of Pennsylvania (Philadelphia, PA), may also use this reference book to teach the technology of ADDM algorithms within the context of a high-level overarching course in future technologies. Second, the book targets policy makers in NIT within the industry, military, and government and aims to educate them from a fundamental perspective, in an intensive short-course style, on the nature, scope, potential, and limits of NIT systems. Third, the monograph offers to managers, consultants, and other professionals of the NIT industry successful examples of NIT system design, analysis of their performance, and the design of unique measures of performance. To practitioners, the book presents an integrated approach to the issues of algorithm design, distributed systems, and concurrent processing.

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